

## RESEARCH ARTICLE

# Community structure and population dynamics of small mammals in an urban-sylvatic interface area in Rio de Janeiro, Brazil

Rosana Gentile<sup>1</sup>, Thiago S. Cardoso<sup>2</sup>, Sócrates F. Costa-Neto<sup>3,4</sup>,  
Bernardo R. Teixeira<sup>1</sup>, Paulo S. D'Andrea<sup>1</sup>

<sup>1</sup>Laboratório de Biologia e Parasitologia de Mamíferos Silvestres Reservatórios, Instituto Oswaldo Cruz, Fundação Oswaldo Cruz. Avenida Brasil 4365, 21040-360 Rio de Janeiro, RJ, Brazil.

<sup>2</sup>Programa de Pós-Graduação em Ciências Veterinárias, Universidade Federal Rural do Rio de Janeiro. Rodovia BR 465, km 7, 23851-970 Seropédica, RJ, Brazil.

<sup>3</sup>Programa de Pós-Graduação em Biodiversidade e Saúde, Instituto Oswaldo Cruz, Fundação Oswaldo Cruz. Avenida Brasil 4365, 21040-360 Rio de Janeiro, RJ, Brazil.

<sup>4</sup>Campus FIOCRUZ da Mata Atlântica, Fundação Oswaldo Cruz. Estrada Rodrigues Caldas 3400, 22713-375 Rio de Janeiro, RJ, Brazil.

Corresponding author: Rosana Gentile (rgentile@ioc.fiocruz.br)

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**ABSTRACT.** The Atlantic Forest is one of the most disturbed Brazilian biomes, with 183 out of 298 species of mammals occurring in the state of Rio de Janeiro. In this study, we aimed to characterize the diversity, community structure, and habitat use of small mammals in the FIOCRUZ Atlantic Forest Campus (CFMA), including areas of Pedra Branca State Park (PBSP, subunit Pau da Fome), state of Rio de Janeiro. We also compared species diversity and composition between two moments 15 years apart (2001 and 2012–2015) and analyzed the population dynamics of the marsupial *Didelphis aurita* (Wied-Neuwied, 1826). Small mammal captures were made in different habitats: sylvatic-urban interface areas near human dwellings, disturbed forest, and preserved forest areas. Five marsupial species and four rodent species were captured in both periods. There was a reduction in species richness and  $\beta$  diversity between the two periods, indicating that disturbances in the environment over the years may have affected the small mammal community structure. The most altered environment showed the greatest species richness and abundance, while the forest areas showed the smallest values, which may be explained by the loss of mammal species, mainly specialist species in forested areas. We identified three groups of species according to habitat preferences: one related to environments with a higher density of vegetation in upper strata – *Marmosa paraguayana* (Tate, 1931) and *Monodelphis americana* (Müller, 1776), another related to a higher density in lower forest strata – *Akodon cursor* (Winge, 1887), and another with no association with the investigated habitat variables – *D. aurita* and *Oligoryzomys nigripes* (Olfers, 1818). The small mammal community structure showed a low level of nestedness in both sampling periods. This study is the first report to evaluate the community structure of small mammals in the sylvatic-urban interface area of Pedra Branca State Park, the largest forest reserve within an urban area in Brazil. The surveys indicate that the small mammal diversity was low in both sampling periods and in both areas, and a species loss in the Pau da Fome locality was observed, despite it is a conservation unit. The greater species abundance and richness in the most disturbed areas suggest an increase of factors favoring the occurrence of synanthropic and opportunistic species.

**KEY WORDS.** Atlantic Forest, diversity, habitat disturbance, marsupials, rodents

## INTRODUCTION

The continuous process of urbanization and expansion of human activities into forest areas leads to changes in the natural habitats, altering species diversity and abundance patterns (Soule

and Wilcox 1980, Ewers and Didham 2006, Devictor et al. 2008). In disturbed ecosystems, generalist and opportunistic species can be favored, increasing their densities and dispersion to rural or peridomicile areas. These patterns may have important consequences for conservation (Umetsu and Pardini 2007) by excluding

more specialist species from the communities; for economics by increasing the number of agricultural pests (Stenseth et al. 2003); and for public health by changing the natural prevalence of zoonotic pathogens in wild reservoirs (Thompson 2013).

The fragmentation and degradation of natural habitats have been occurring quite rapidly for decades in tropical regions. This process has several effects on the demography, genetic structure of populations, and geographic distribution of a species, leading to changes in its community structure. As a result, the process of species extinction may be accelerated, biodiversity may be reduced, or community species composition may be altered by the introduction of invasive species. Local extinction would occur not only by the total elimination of a species' habitat, but, mainly, by the accumulated effects on small populations.

The Atlantic Forest is considered one of the hotspots of biodiversity on the planet (Myers et al. 2000) due to its species richness, number of endemic species, and degree of threat (Mittermeier et al. 1998). It is one of the most disturbed Brazilian tropical biomes, with the largest number of endangered species by area until the most updated available information (Bergallo et al. 2000, Myers et al. 2000). Habitat fragmentation and degradation related to human activities have occurred for hundreds of years, reducing the biome's original area by about 93% (Fundação SOS Mata Atlântica and INPE 2016). In the state of Rio de Janeiro, the removal of forested areas reached approximately 81% of the original cover, with only about 814,563 ha remaining (Fundação SOS Mata Atlântica and INPE 2016). The state of Rio de Janeiro constitutes a strategic portion along the continuum of remnants of the Atlantic Forest because it incorporates high species richness and endemism for different groups of animals (Rocha et al. 2003).

Concerning the mammals, 298 species are recognized in the Atlantic Forest (Fundação SOS Mata Atlântica and INPE 2016) and 42 are considered as threatened (Chiarello et al. 2008), with 183 occurring in the state of Rio de Janeiro, at least three of which are endemic to the state (Rocha et al. 2003). These data indicate that this region is an area of high richness of mammal species. Medium and large mammals are extremely threatened by hunting and habitat disturbance (Fonseca et al. 1994, Cullen et al. 2000, 2001) because of their position in the trophic chain and their widespread habitat needs. In some localities of the Atlantic Forest, populations of these species disappeared completely, leading to changes in ecological interactions and likely increasing the abundance of generalist species of small mammals, such as the common opossum *Didelphis aurita* (Wied-Neuwied, 1826) (Fonseca and Robinson 1990, Gentile et al. 2004).

These factors make the Atlantic Forest remnants extremely important for biological conservation in the State of Rio de Janeiro. In this study, we aimed to characterize the diversity and community structure of small mammals, also evaluating their habitat use, in a sylvatic-urban interface area of the FIOCRUZ Atlantic Forest Campus (CFMA) of the Oswaldo Cruz Foundation

(Campus FIOCRUZ Mata Atlântica – CFMA) and its surroundings, including areas of Pedra Branca State Park (PBSP), state of Rio de Janeiro. Herein, we also compared species diversity and composition between two moments, 15 years apart (2001 and 2012–2015), and analyzed the population dynamics of *D. aurita*, the most abundant and constant species throughout the study. To understand the community structure of small mammals and how the species are related to different habitat types, we addressed five inter-related questions: (1) Does diversity or species composition vary among habitat types? (2) What is the pattern of the community structure of the small mammals? (3) Did diversity, species composition and community structure varied between 2001 and 2012–2015 samplings? (4) Are small mammal species more related to a specific area or habitat variable? (5) Is there any influence of habitat heterogeneity on the mammal assemblage structure?

## MATERIAL AND METHODS

The study was carried out in areas of the CFMA and surroundings, encompassing areas of the FIOCRUZ Atlantic Forest Biological Station (EFMA) and PBSP in the municipality of Rio de Janeiro. The CFMA is part of the buffer zone of PBSP, including preserved areas of the park, and is also adjacent to an expanding urban region in the western area of Rio de Janeiro. The area that today comprises the CFMA has been previously used for sugarcane mills and coffee farms, with construction of large residences and roads. In the 20<sup>th</sup> century, a psychiatric colony with various urban facilities was established. In 2003, the area was incorporated to FIOCRUZ, and from then on, non-edification areas were defined and a more effective process of environmental protection and recovery was established in order to mitigate the effects of anthropic impacts. Thus, the 2001 samplings preceded this area management and conservation program, and the 2012–2015 samplings were carried out a decade after the implementation of this program. PBSP is the largest forested reserve located within an urban environment in Brazil. It covers an area of 12,492 ha, and the predominant phytophysiology is Ombrophilous Dense Atlantic Forest vegetation. PBSP was created in 1974. Although the region was also occupied by sugarcane and coffee cycles in the colonial period, part of this forest was preserved in 1908 as a protection for the hydric resources. In the last decade, with the population growth of the surrounding area, expansion of low-sanitation communities, implementation of major structuring works and increase of the road network, the area began to suffer great anthropic pressure from the surrounding area. These factors have impacted on the quality and structure of the forest borders and boundary areas of the PBSP, including the areas of our study. Currently, those border areas have a disturbed forest with little understory and sparse midstory.

Small mammal captures were made in transects inside the CFMA and PBSP (subunit Pau da Fome), in areas with different habitat characteristics: (1) sylvatic-urban interface areas near

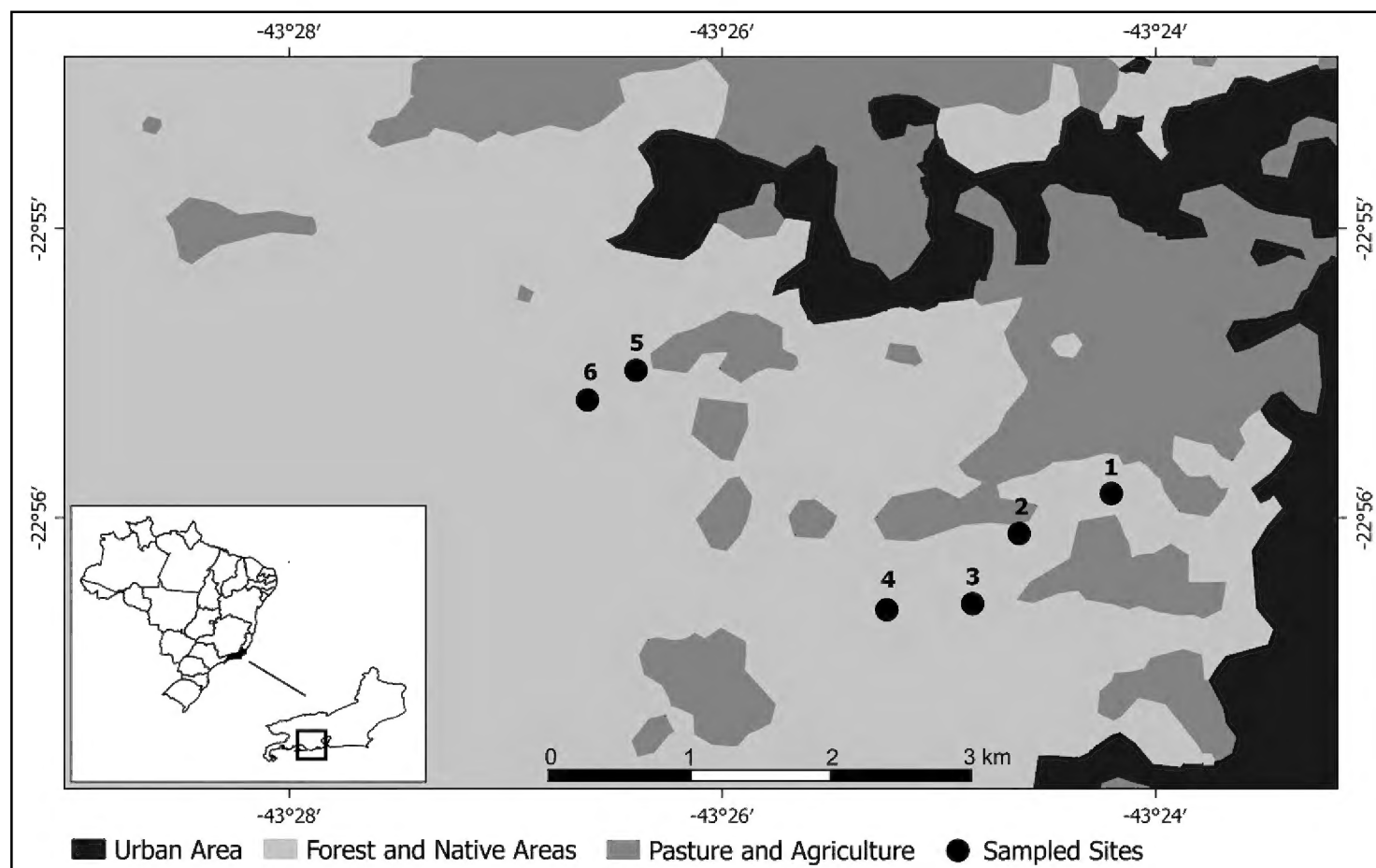


Figure 1. Map of the study area indicating the sampling localities in CFMA and Pau da Fome region, State of Rio de Janeiro, Brazil. 1) CFMA – Peridomicile, 2–3) CFMA – Disturbed Forest, 4) CFMA – Preserved Forest, 5) Pau da Fome – Peridomicile, 6) Pau da Fome – Disturbed Forest.

human dwellings (peridomicile) in the CFMA and Pau da Fome ( $22^{\circ}56'18''\text{S}$   $43^{\circ}24'11''\text{W}$  and  $22^{\circ}55'57''\text{S}$   $43^{\circ}26'34''\text{W}$ ), (2) disturbed forest areas in the CFMA and Pau da Fome ( $22^{\circ}56'28''\text{S}$ ,  $43^{\circ}24'34''\text{W}$ ;  $22^{\circ}56'45.5''\text{S}$   $43^{\circ}24'45.6''\text{W}$  and  $22^{\circ}55'57''\text{S}$ ,  $43^{\circ}26'36''\text{W}$ ), and (3) preserved forest areas in the CFMA ( $22^{\circ}56'47''\text{S}$ ,  $43^{\circ}25'07''\text{W}$  and  $22^{\circ}56'41''\text{S}$ ,  $43^{\circ}24'52''\text{W}$ ) (Fig. 1).

The preserved forest areas presented a vegetation canopy ranging from 10 to 40 m and an irregular slope varying from flat to steep. The disturbed forest areas were in the regeneration process, with vegetation in different ecological succession stages located between areas of human occupation and preserved areas. They had a medium vegetation height ranging from 6 to 20 m and a flat slope. The peridomicile areas were located in the backyards of houses and had a lower canopy than the other areas, ranging from 6 to 15 m, a predominance of bushes and small trees, some flooded areas, and a flat to moderate slope. In all areas, the understory was sparse to semi-open in most transects. The climate of the region is humid mesothermal, with hot, rainy summers and mild winters.

The study was done in two periods: in 2001, with two samplings in each area; and between 2012 and 2015, with two samplings in Pau da Fome and six in the CFMA in all habitat types. Small mammal captures were carried out in 20-point transects established in different habitat types. Capture points were equidistant, 15 m apart, with two traps per point on the ground: a Sherman ( $7.62\text{ cm} \times 9.53\text{ cm} \times 30.48\text{ cm}$ ) and a Tomahawk ( $40.64 \times 12.70 \times 12.70\text{ cm}$ ), both suitable for the capture of live animals up to 3 kg. Each trapping session lasted five consecutive

Table 1. Trapping effort for the 2001 and 2012–2015 samplings in CFMA and Pau da Fome for each type of habitat, Rio de Janeiro, Brazil.

Area\Period	2001 Samplings	2012–2015 Samplings
CFMA total	2325	7840
CFMA peridomicile	913	2400
CFMA disturbed forest	1412	3040
CFMA preserved forest	–	2400
Pau da Fome total	1125	1280
Pau da Fome peridomicile	–	640
Pau da Fome disturbed forest	1125	640

nights, except for one sampling in 2001 in the CFMA, which lasted 10 nights. The bait used was composed of a mixture of bacon, oats, bananas, and peanut butter. Trapping effort for each area and sampling period are better described in Table 1.

The captured animals were anesthetized, euthanized, and had their bionomic data collected (age, sex, reproductive activity, body mass, and external measurements, such as body, tail, foot and ear lengths) in a laboratory field base. Young animals, lactating females and specimens exceeding the limit of the capture license (only *D. aurita*) were marked with ear-tags and released at their trapping points. All the other animals were taxidermized and deposited as voucher specimens in the scientific collection of the Department of Vertebrates of the National Museum of Rio de Janeiro. Specimens were identified by external and cranial morphology. Rodent species of the genus *Akodon* Meyen, 1833 were identified by their diploid number after karyotyping.



Animals were captured under authorization of the Brazilian Government's Chico Mendes Institute for Biodiversity and Conservation (ICMBIO, license number 13373) and the Environmental Institute of Rio de Janeiro State (INEA, license number 020/2011). All procedures followed the guidelines for the capture, handling, and care of animals of the Ethical Committee on Animal Use of the Oswaldo Cruz Foundation (CEUA, licenses number P-0083-01, L-049/08, LW81/12, and LW-39/14). Biosafety procedures and personal safety equipment were used during all procedures involving animal handling and biological sampling.

Microhabitat variables were measured at each trapping point, considering an area of 9 m<sup>2</sup> around the traps only for the 2012–2015 period, and only for the CFMA transects. The variables were measured at two points, 1.5 m apart, within each trap station according to a modified version of Freitas et al. (2002) method. Nine quantitative variables were measured: percentage of vegetation cover on the soil (VCS), percentage of litter (LITT), percentage of exposed soil (SOIL), percentage of rocks (ROCK), percentage of canopy cover (CANO), canopy height (CAHE), number of trees with diameter at breast height  $\geq 5$  (TREE), number of fallen trunks (TRUN), and vertical vegetation obstruction at 50 cm to 1 m (VVO). The variables were measured using a wire square of 0.5  $\times$  0.5 m divided into 100 smaller squares, as proposed by Freitas et al. (2002). We quantified the frequency of squares occupied by each variable, except for CAHE, which was measured in meters, and TREE and TRUN, which were directly counted in numbers.

Population dynamics were analyzed in the 2012–2015 period only for the opossum *D. aurita*, which was the most abundant species. The sex ratio was tested by chi-square test. The reproductive activity was analyzed, considering the presence of lactating females. The age structure analysis was performed by dividing the animals into age classes according to dental development classes and reproductive condition according to Gentile et al. (1995).

Trapping success was calculated as the number of captured animals divided by the number of trap-nights multiplied by 100. The species richness was considered as the number of species observed during the study. In addition, a species richness index was estimated using the Jackknife 1 method (Palmer 1990). Estimators were calculated for the 2001 and 2012–2015 data using the “vegan” package (Oksanen et al. 2016) of RStudio software, version 0.99.902. The relationship between abundance and species richness was investigated for the two periods using Spearman's correlation. In this case, abundance values were standardized by considering the total trapping effort of each transect.

Species diversity between areas and between the 2001 and 2012–2015 samplings were compared using Nonmetric Multidimensional Scaling (NMDS), with the “stats” package of RStudio software, version 0.99.902 (R Core Team 2017). The Gower distance measure was used for the relative abundances

of the species, considering a stress value of up to 0.2. Only for this analysis, relative abundances were calculated by dividing the abundance value of each species by the abundance of the most abundant species for each case based on Williams et al. (2002). We also calculated the total Whitaker  $\beta$  diversity and the  $\beta$  diversity between each transect pair for 2001 and 2012–2015, separately. These analyses were done in Past software, version 3.08 (Hammer et al. 2001).

The habitat variables were transformed into a standard area unit according to Cerqueira and Freitas (1999). Subsequently, habitat heterogeneity indexes for each CFMA transect were calculated according to Paglia et al. (1995). The variance of each habitat variable per transect was divided by the total variance of that variable, considering all transects. Then, these quotients were added for all the variables in each transect in order to obtain a heterogeneity index. The relationship between habitat heterogeneity and species richness was investigated using Spearman's correlation.

In order to investigate the relationship among the abundances of small mammals, the habitat variables, and the areas, abundance data were ordered along the canonical axes of a Canonical Correspondence Analysis (CCA), according to its ecological optima (Borcard et al. 2011). The analysis was performed using the means of each habitat variable for each transect. Before ordering, correlated and multimodal variables were excluded. The CCA was made with the following variables: VCS, VVO, CANO, and TREE. The rodent *Rattus rattus* (Linnaeus, 1758) was not included in this analysis. The correlation analysis was done with the “Hmisc” package (Harrell 2016) and the CCA with “Vegan” package (Oksanen et al. 2016) of RStudio software, version 0.99.902, only for the CFMA-2012–2015 data.

The mammalian community structure was investigated for both the 2001 and 2012–2015 data, separately, using the abundance data standardized for trapping effort. The structure was analyzed based on the nesting measure using the weighted “NODF” method (Almeida-Neto and Ulrich 2011) in the “Bipartite” package (Dormann et al. 2008) of RStudio software, version 0.99.902.

## RESULTS

### Species composition

In 2001, eight small mammal species were captured, seven in the CFMA and four in Pau da Fome (Table 2). In the 2012–2015 period, seven species of small mammals were captured, seven in the CFMA and two in Pau da Fome (Table 2). Species captured during both periods of the study were *D. aurita*, *Gracilinanus microtarsus* (Wagner, 1842), *Metachirus nudicaudatus* (Desmarest, 1817), *Marmosa (Micoureus) paraguayana* (Tate, 1931), *Monodelphis americana* (Müller, 1776) (Didelphimorphia: Didelphidae), *Akodon cursor* (Winge, 1887), *Oligoryzomys nigripes* (Olfers, 1818) (Rodentia: Sigmodontinae), *Coendou spinosus* (F. Cuvier, 1823) (Rodentia: Erethizontidae), and *R. rattus* (Rodentia: Muridae).

Table 2. Number of individuals captured in 2001 and 2012–2015 in CFMA and Pau da Fome, Rio de Janeiro, Brazil. Numbers in parenthesis are the abundances in relation to the trapping effort of each area multiplied by 100.

Species	CFMA 2001	Pau da Fome 2001	CFMA 2012–2015	Pau da Fome 2012–2015
<i>Didelphis aurita</i>	34 (1.46)	8 (0.711)	76 (0.969)	14 (1.094)
<i>Marmosa paraguayana</i>	1 (0.043)	1 (0.089)	4 (0.051)	0
<i>Metachirus nudicaudatus</i>	0	1 (0.089)	1 (0.013)	0
<i>Gracilinanus microtarsus</i>	1 (0.043)	1 (0.089)	0	0
<i>Monodelphis americana</i>	1 (0.043)	0	2 (0.026)	0
<i>Akodon cursor</i>	7 (0.301)	0	7 (0.089)	0
<i>Oligoryzomys nigripes</i>	4 (0.172)	0	5 (0.064)	2 (0.156)
<i>Coendou spinosus</i>	1 (0.043)	0	0	0
<i>Rattus rattus</i>	0	0	7 (0.090)	0

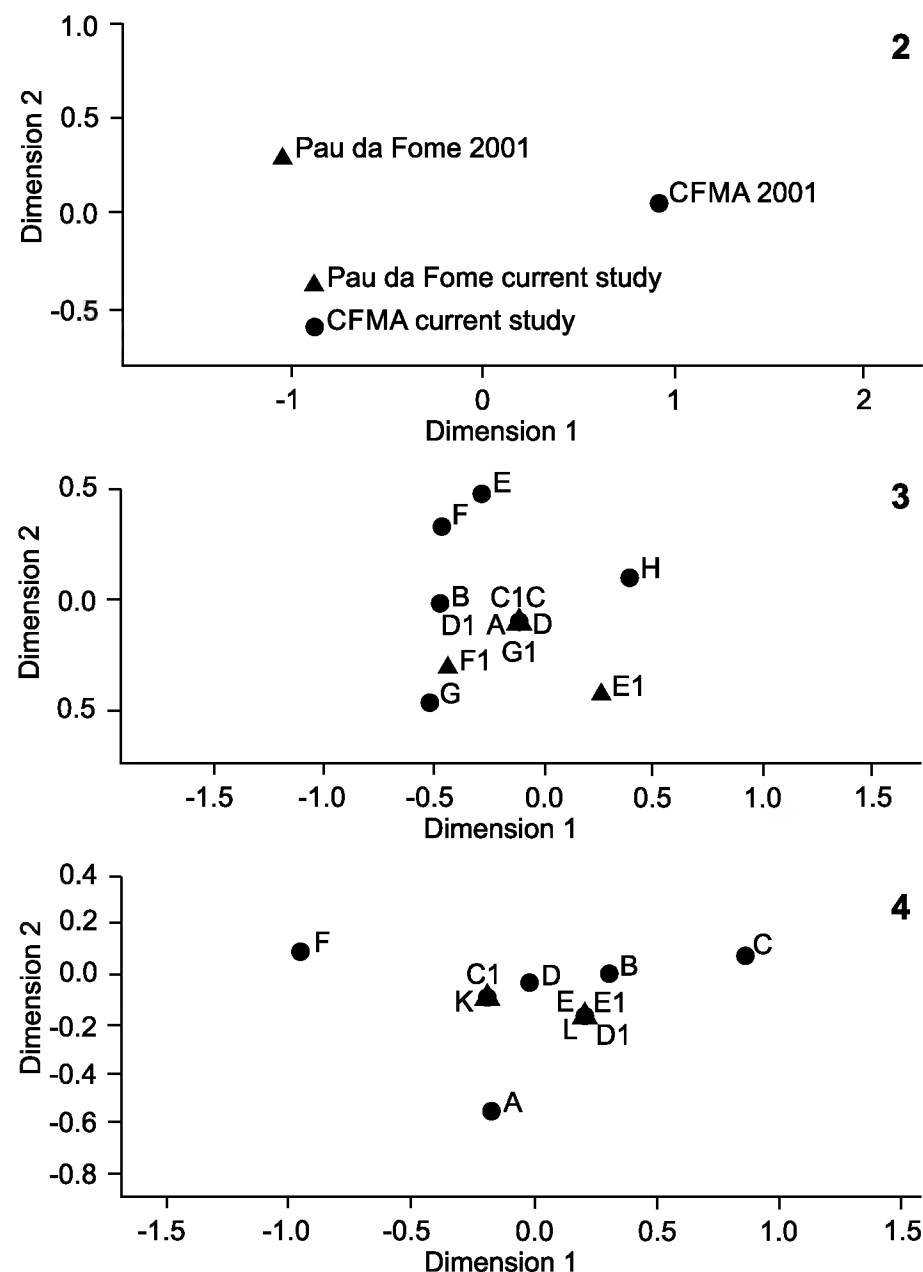
The most abundant species in both periods and in both areas was *D. aurita*, captured in all areas and in all samplings. The species *G. microtarsus* and *C. spinosus* were not captured in the most recent period, whereas *R. rattus* was captured only in 2012–2015, since during this period routine samplings were made in peridomicile areas. Four species of marsupials were captured in Pau da Fome in 2001, while only *D. aurita* and *O. nigripes* were recorded in 2012–2015 (Table 2).

The trapping success was 2.11% in the CFMA and 0.98% in Pau da Fome in 2001. In the 2012–2015 period, the trapping success was 1.42% in the CFMA and 1.25% in Pau da Fome. The trapping success was higher in the peridomicile areas (2.38%), followed by the disturbed forest areas (1.33%), and the lowest trapping success was in the preserved forest areas (0.54%).

#### Diversity analysis

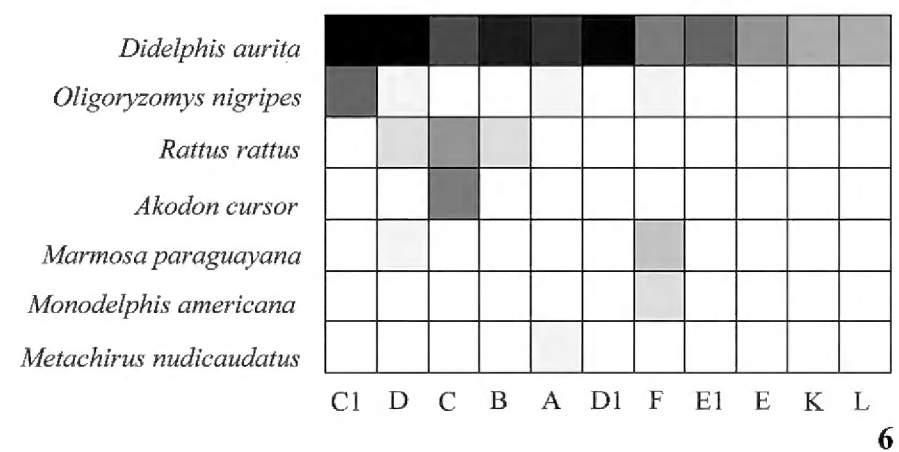
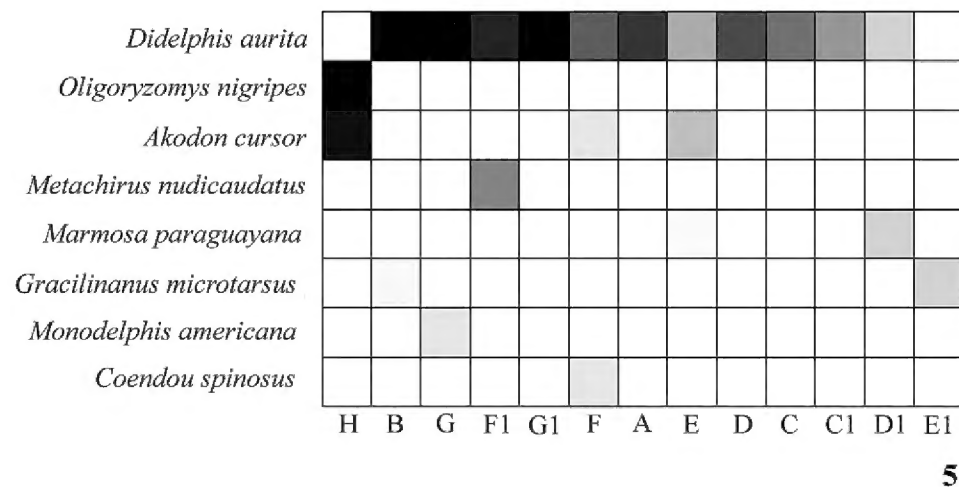
Species richness estimated for 2001 using Jackknife 1 was 10.5 (SD = 2.69), and for 2012–2015 it was 7.875 (SD = 0.875). Thus, the estimated richness was closer to the observed richness for 2012–2015 samplings, probably because there were more samplings in this period. Abundance was correlated with species richness only for the 2001 data (2001:  $r_s = 0.622$ ,  $p = 0.013$ ; 2012–2015:  $r_s = 0.410$ ,  $p = 0.210$ ).

In the NMDS analyses carried out to compare the species composition and relative abundance of species between the two periods and the two areas (the CFMA and Pau da Fome), we observed a greater similarity between CFMA-2012–2015 and PF-2012–2015 and a greater difference between CFMA-2001 and PF-2001 (Fig. 2). Comparing the diversity among the transects in 2001, we observed little discrepancy, except for the only peridomicile transect (H) sampled in the CFMA in that period and a disturbed forest transect in Pau da Fome (E1) (Fig. 3). Considering the transects of the more recent samplings, the NMDS analysis showed little variation among transects, except for a peridomicile (C), a preserved forest (F) and a disturbed forest transect (A) in the CFMA, which were more discrepant



Figures 2–4. Plots of the Non-metric Multidimensional Scaling Analysis between the two periods and areas studied (● CFMA and ▲ Pau da Fome) for the small mammal species: (2) comparison between 2001 and 2012–2015 samplings including all transects pulled; (3) comparison among transects in 2001 (transects from A to D in disturbed forests and from E to H in peridomicile areas of CFMA; transects from C1 to G1 in disturbed forest of Pau da Fome); (4) comparison among transects for the 2012–2015 period (transects A, B, K, L in disturbed forest areas of CFMA; E1 in disturbed forest areas of Pau da Fome; C, D in peridomicile areas of CFMA; C1 and D1 in peridomicile areas of Pau da Fome; E and F in preserved forest areas of CFMA).

from the others (Fig. 4). The  $\beta$  diversity was higher for the 2001 samplings (4.45) than for the recent ones (2.2). The highest values of  $\beta$  diversity for 2001 occurred among three transects (with the lowest abundance of captures) with all the others, and among the only peridomicile transect in the CFMA of that period (which presented a great abundance of *A. cursor* and *O. nigripes*) with all the others. For the 2012–2015 period, the greatest  $\beta$  diversities were between a disturbed forest transect in the CFMA, a preserved forest transect in the CFMA, and a peridomicile transect in Pau da Fome, and between two peridomicile transects, one in CFMA and another in Pau da Fome.



Figures 5–6. Small mammal community structure in CFMA and Pau da Fome, Rio de Janeiro, Brazil, for the (5) 2001 and (6) 2012–2015 samplings. (A, B, C, D, E, F, G, H, K, L) CFMA transects, (C1, D1, E1, F1, G1) Pau da Fome transects.

### Community structure

The small mammal community structure showed a small level of nestedness for both the 2001 (weighted NODF = 19.02,  $p = 0.001$ ) and 2012–2015 (weighted NODF = 44.95,  $p = 0$ ) data, and the null model test was significant in both analyses (Figs 5–6). For the most recent period, the most common and the synanthropic species, *D. aurita* and *R. rattus*, respectively, and the opportunistic rodent, *O. nigripes*, formed a species subset and were closer to the nesting pattern, while the most specialist species did not follow the pattern and seemed to indicate competitive exclusion (Fig. 6). For 2001, the model was even less nested; however, the most common species, *D. aurita*, followed a small level of nestedness, while the others followed a completely random pattern (Fig. 5).

### Habitat analysis

Habitat heterogeneity was not related to the type of environment (Table 3) nor correlated with species richness ( $r = 0.27831$ ,  $p = 0.59332$ ). On the other hand, the canonical correspondence analysis (CCA) showed a relationship among species, transects, and habitat variables. The first two axes together explained approximately 75% of the data variation (Eigenvalues: CCA1 = 0.4674 and CCA2 = 0.2841). The marsupials *M. paraguayana* and *M. americana* were strongly related with the presence of trees (TREE), a closed canopy (CANO), and a preserved forest transect. *A. cursor* was related to closed understory (VVO) and peridomicile areas. *D. aurita*, which was the most abundant and constant species in all transects, and *O. nigripes*, which was also present in most transects, were in the center of the plot, indicating a relationship with most of the areas but with no specific habitat variable. *Metachirus nudicaudatus* showed no relationship with the variables; however, only one individual of this species was captured in a disturbed forest transect (Fig. 7, Tables 4–5).

### Population dynamics

In relation to the population dynamics of the marsupial *D. aurita*, the sex ratio of captured individuals did not differ

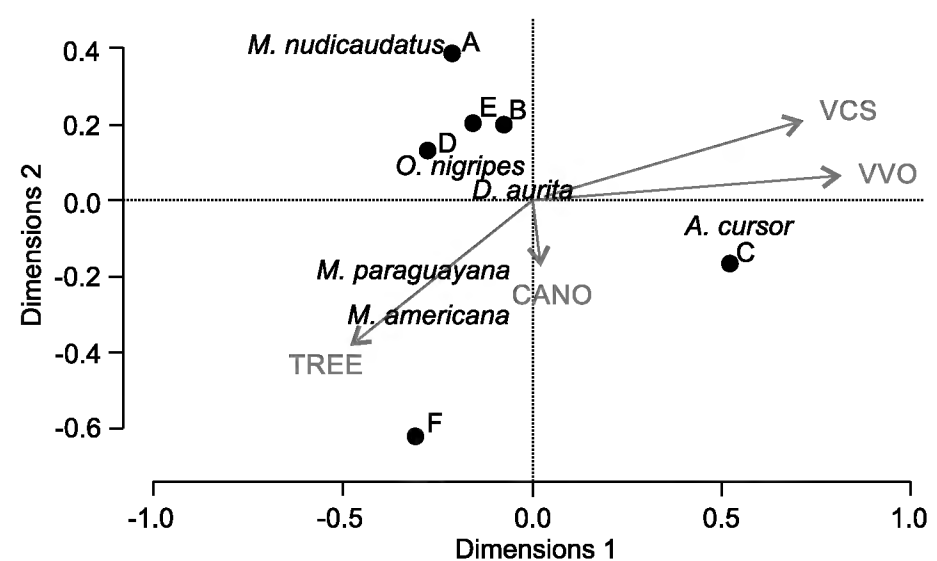


Figure 7. Canonical correspondence analysis (CCA) and relationship among species, transects (A, B, C, D, E, F) and habitat variables (CANO – percentage of canopy cover; TREE – number of trees with diameter at breast height  $\geq 5$ ; VCS – percentage of vegetation cover on the soil; VVO – vertical vegetation obstruction) for the 2012–2015 period in CFMA, Rio de Janeiro, Brazil.

from 1: 1 ( $\chi^2 = 0.23$ ,  $p = 0.630$ ,  $df = 1$ ). The largest abundances were observed in July. The highest proportions of females in the reproductive stage were also observed in July, which is the beginning of the breeding season (period when females are fertile and receptive to copulate with males), when almost all adult females (except one) were lactating, as well as in November (Fig. 8). Considering the autumn samplings, only one lactating female was found in April 2013 (Fig. 8). Pouch young were present in the months of July and November, as well as in April 2013 in low abundance (Fig. 9). Young individuals were absent in July samplings. Subadult animals were recorded in almost all the sampling occasions. Although adults occurred throughout the study, they were more abundant in July and November (Fig. 9).

## DISCUSSION

The small mammal species richness observed was similar between 2001 (8) and 2012–2015 (7), although the estimated richness (10) was slightly higher for the 2001 period. However,



Table 3. Environmental heterogeneity and species richness for each transect for the 2012-2015 period in CFMA, Rio de Janeiro, Brazil.

Transect	Heterogeneity	Richness	Habitat type
A	7.52	3	Disturbed forest
B	4.52	2	Disturbed forest
C	8.45	3	Peridomicile
D	4.30	4	Peridomicile
E	4.68	1	Preserved Forest
F	6.46	4	Preserved Forest

Table 4. Environmental variables loadings on canonical axes after Canonical Correspondence Analysis scores for constraining variables analyzed for the 2012-2015 period in CFMA, Rio de Janeiro, Brazil.

Variables	CCA1	CCA2
VCS	-0.5560	0.3423
CANO	0.2433	-0.7322
TREE	0.4739	-0.4088
VVO	-0.9148	0.1490

Table 5. Canonical Correspondence Analysis scores for the small mammals analyzed for the 2012-2015 period in CFMA, Rio de Janeiro, Brazil.

Species	CCA1	CCA2
<i>Didelphis aurita</i>	0.0461	0.0852
<i>Marmosa paraguayana</i>	0.8709	-0.7700
<i>Metachirus nudicaudatus</i>	0.3440	1.5516
<i>Monodelphis americana</i>	1.0601	-1.1246
<i>Akodon cursor</i>	-2.0658	-0.3771
<i>Oligoryzomys nigripes</i>	0.5692	0.2404

there was a reduction in species richness in Pau da Fome due to the absence of captures of the marsupials *G. microtarsus*, *M. paraguayana*, and *M. nudicaudatus* in the recent samplings, as well as a reduction of  $\beta$  diversity between the two periods. The lack of correlation between species abundance and richness for the most recent period may also indicate that disturbances in the environment are continuously occurring in spite of both areas are under conservation measures, affecting the small mammal community structure, as discussed hereafter.

Another small mammal survey, also carried out in several altitudes of PBSP by Oliveira et al. (2012), registered the occurrence of 10 species of wild small mammals from 2005 to 2007, with a similar dominance of *D. aurita*. The species richness was similar to our study; however, the species composition showed a few differences. Oliveira et al. (2012) reported *Marmosops incanus* (Lund, 1840), *Philander frenatus* (Olfers, 1818), and *Guerlinguetus brasiliensis* (Gmelin, 1788), which were not captured in the present study, although the last one was visually recorded in 2001. Moreover, *G. microtarsus* was captured in the

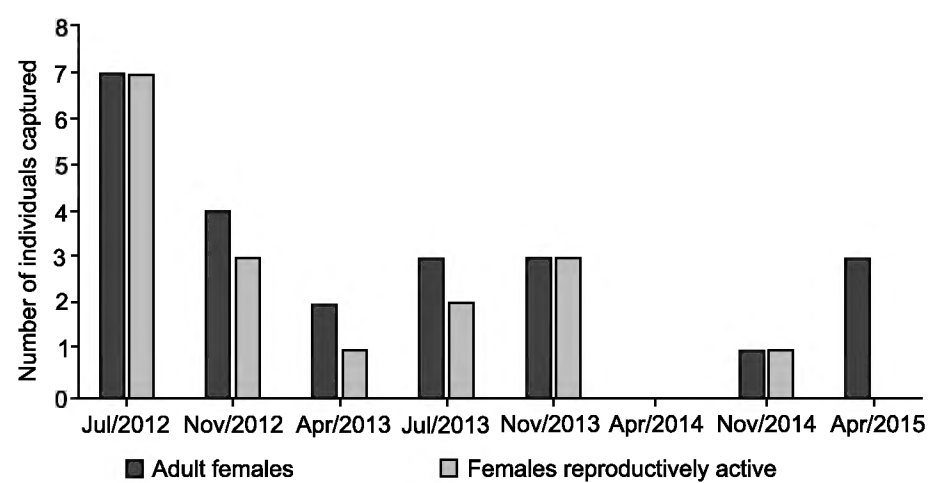


Figure 8. Proportion of reproductively active females of the marsupial *Didelphis aurita* for the 2012–2015 period in CFMA and Pau da Fome, Rio de Janeiro, Brazil.

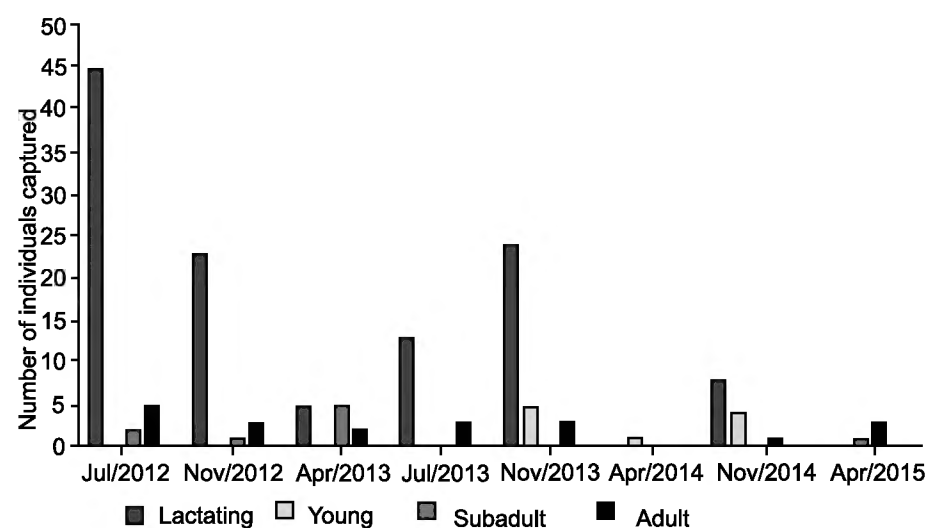


Figure 9. Age structure of the marsupial *Didelphis aurita* for the 2012–2015 period in CFMA and Pau da Fome, Rio de Janeiro, Brazil.

present study, but not in Oliveira et al. (2012). Considering all the information gathered, we may consider a total of 11 wild non-volant small mammals observed in PBSP so far, excluding the two invasive *Rattus* species. When comparing the species richness in this study with other studies of small mammals in the Atlantic Forest, some of which, carried out in continuous forest areas, they related more than 20 species (23 in Pardini and Umetsu 2006, 26 in Machado et al. 2013, 21 in Maestri et al. 2014), meanwhile we observed a very low species richness, especially of rodents.

The results of the NMDS analyses indicated a greater difference in species diversity when compared the 2001 with the 2012–2015 sampling periods than among localities. Comparing the localities within each period, the greater discrepancies were observed between peridomicile areas in the CFMA and the other transects, which was expected since the peridomicile areas represent a different environment with more distinct characteristics when compared to the preserved and disturbed forest environments. However, the peridomicile areas, which are the most altered environments, showed the greatest species richness and abundance, while the forest areas showed the smallest values.

We suggest two hypotheses. The direct or indirect impact caused by anthropic activities in the studied forested areas could result in a process of loss of mammal species, mainly the specialist ones, leading to a phenomenon known as empty forest (Redford 1992). Another possibility is that the occasional captures of some species in the forest environment is due to the limits of the dispersion of the individuals coming from more preserved areas in the interior of the forest. The latter hypothesis could explain the only capture of *M. nudicaudatus* during the study, because this species may roam large areas inside their habitats (Gentile and Cerqueira 1995).

The greater abundance and richness of species in the most disturbed areas suggest an increase of factors favoring the occurrence of generalist and synanthropic species, such as *D. aurita* and the introduced rodent *R. rattus*, which are frequently found in areas close to human dwellings, in addition to the opportunistic rodents *A. cursor* and *O. nigripes*. The highest trapping success observed for the most disturbed areas may also be associated with the conditions present in these areas, which favored the greater abundance and occurrence of these species. The occurrence of *D. aurita* and *O. nigripes* in the three types of environment indicates an opportunistic and plastic character in relation to the present environmental conditions of the areas. These results highlight the importance of a continuous monitoring in the areas, since these species are widely known as reservoir of zoonotic pathogens in the state of Rio de Janeiro (Vaz et al. 2007, Oliveira et al. 2009, 2017).

The marsupial *D. aurita* showed much greater abundance compared to the other species and was present throughout the study. Its greater abundance in the peridomicile areas supports other studies that have reported its presence as a dominant species of small mammal communities in disturbed areas (Cáceres and Monteiro-Filho 1998, Gentile et al. 2000). Other studies conducted in sylvatic-urban interface areas around Serra dos Órgãos National Park also recorded the occurrence of this marsupial in high abundance (Gentile et al. 2004, Kajin et al. 2008).

The population dynamics of the common opossum in this study were similar to those in other studies carried out in Atlantic Forest areas, where the greatest abundances of this marsupial were usually recorded between May and August, at the end of the rainy season, and during the dry season (Cáceres and Monteiro-Filho 1997, Gentile et al. 2000, Graipel and Santos-Filho 2006, Bonecker et al. 2009). This pattern could be related to the capture of young and subadults born in the previous reproductive season. In other studies of population dynamics of *D. aurita* in the state of Rio de Janeiro, the opossum also presented a pattern of seasonal reproduction (Cerqueira 2005), with a reproductive period usually beginning in July to August and ending in March to April (Gentile et al. 1995, Macedo et al. 2007, Kajin et al. 2008).

The habitat structure based on its heterogeneity did not show a relationship with the species richness, indicating that the degree of habitat heterogeneity may have varied within each environment. However, this analysis allowed us to identify three

groups of species: one related to environments with a higher density of vegetation in upper strata, another related to a higher density in lower forest strata, and another with no association with the investigated habitat variables, as discussed below.

Although the occurrence of *D. aurita* is associated with the presence of certain variables in the environment (Gentile and Fernandez 1999, Gentile et al. 2004, Freitas et al. 1997), no association of this species was observed with the habitat variables in the present study. The higher abundance of the rodents *O. nigripes* and *A. cursor* in areas with greater anthropic influence (peridomicile), also confirms the opportunistic nature of these species in relation to habitat occupancy, as previously observed in disturbed regions and along forest borders (Olifiers et al. 2005, Vaz et al. 2007, Geise 2012, Cardoso et al. 2016, Gonçalves et al. 2016). However, *A. cursor* showed more association with habitat variables, such as a close vegetation near the ground, which can provide shelter, protection against predators, and food resources (Dalmagro and Vieira 2005, Lima et al. 2010, Melo et al. 2013), a higher vegetation density in the understory and an open canopy, which are characteristic of open areas (Cirelli and Penteado-Dias 2003).

The marsupial *M. nudicaudatus* was one of the least abundant species in the study area, although it was recorded in both sampling periods. Other studies also reported a low abundance of this species in the Atlantic Forest (Pardini 2004, Caldara-Junior and Leite 2007, Santos-Filho et al. 2012). The very low abundance of this species may have contributed to the lack of association between this species and the environmental variables. However, an association of *M. nudicaudatus* with areas of closed understory (Freitas et al. 1997), lower canopy cover, and a moderate degree of disturbance has already been reported (Moura et al. 2005).

*Marmosa paraguayana*, which is a scansorial marsupial (Paglia et al. 2012) and may occur in forest environments (Prevédello et al. 2008), fragments and is able to cross matrices of grassland (Pires et al. 2002), was also found in low abundance in the preserved forest areas, with only one individual in the peridomicile. The relationship between this species and environments with higher vegetation density in the upper strata was also found by Kajin and Grelle (2012), where the marsupial showed a relationship with areas with a more closed canopy.

The marsupial *M. americana*, also captured in low abundance and only in preserved forest areas, has previously been found in disturbed areas (D'Andrea et al. 1999), although it is more common in forest environments (Alho et al. 1986, Mares et al. 1986). This species exhibited the same habitat associations observed for *M. paraguayana*, which can be characterized by the presence of more trees and a closed canopy. These two species could represent visitor species in this interface area, presenting occasional captures of individuals coming from more preserved areas in the upper parts of the forest.

The absence of traps in the midstory and in the upper strata may have underestimated the occurrence of *G. microtarsus*, since it is an arboreal marsupial (Paglia et al. 2012) and it was captured in low abundance only in 2001 samplings. A study



carried out in the Pantanal biome indicated that the congener species *G. agillis* had significantly more captures in trees than on the ground (Andreazzi et al. 2011).

Nestedness distribution patterns are related to certain community processes because, according to the model, species occurring in species-poor sites are subsets of species occurring in species-rich sites (Patterson and Atmar 1986). The understanding of community structure patterns allows us to evaluate niche specialization, and is an important feature in the study of ecological networks (Sugihara and Ye 2009) and in conservation programs (Patterson 1987, Southwood 1996, Horváth et al. 2011). The observed small mammal community structure presented a pattern of low level of nestedness in both periods, differing from a random pattern, which indicates that some species are dominant along the environmental gradient, such as *D. aurita* and the opportunist rodents. Others might have a stochastic fluctuation in their distributions, which is a characteristic of species poor communities, since less generalist species, such as *M. americana* and *M. paraguayana*, occurred in species-rich sites, especially in the 2012–2015 period.

The higher degree of nestedness recorded for the 2012–2015 data in relation to 2001 may reinforce the higher dominance of the synanthropic and generalist species in the most recent sampling. There is also the possibility that there may be other species not sampled in the study, mainly in the more preserved and upper areas of PBSP. Menezes and Fernandez (2013) also found low nestedness values in a meta-analysis review of mammal communities in fragmented landscapes in different regions of the world. Surveys together with ecological studies on populations and communities are urgent in those areas, not only because of biodiversity concerns but also to expand understanding of the mechanisms of the ecological patterns in multiple scales of spatial-temporal organization, taking into account the metacommunity scale and the patterns and processes that emerge from it (Leibold et al. 2004).

This study is the first report to evaluate the community structure of small mammals in the sylvatic-urban interface area of PBSP, the largest forest reserve within an urban area in Brazil. These surveys indicate that the small mammal diversity was low in both sampling periods in spite of the preservation and forest restoration program recently implemented in CFMA areas, and a species loss in the Pau da Fome locality, despite it is a conservation unit. The greater species abundance in the most disturbed areas suggests the increase of factors favoring the occurrence of synanthropic species, such as *R. rattus*, the generalist marsupial *D. aurita* and the opportunistic rodents, *A. cursor* and *O. nigripes*. These results have important consequences not only for conservation but also for public health, providing potential subsidies for future public policy actions.

## ACKNOWLEDGMENTS

We would like to thank the staff and students of Laboratório de Biologia e Parasitologia de Mamíferos Silvestres

Reservatórios, Laboratório de Hantavírus e Rickettsioses, Laboratório de Biologia de Tripanossomatídeos and Laboratório de Pesquisa Clínica em Dermatozoonose from FIOCRUZ who helped in the field work; to the coordinator of FIOCRUZ Atlantic Forest Campus, Gilson Antunes, for providing local facilities and supporting the general project; to the staff of FIOCRUZ Atlantic Forest Campus, especially to Marta L. Brandão and José L.P. Cordeiro for local facilities and help in the field work; to Marcelo F. Freitas for helping in the field work in all campaigns; to Cibele R. Bonvicino for rodents identification, to Fabiana P. Caramaschi for marsupials identification, to Daniela Dias for the curator of the collected animals, to Natália A. Costa and Fernando O. Santos for helping in the figures edition, to Instituto Estadual do Meio Ambiente (INEA) for the collecting licence and for local facilities and to an anonymous reviewer for suggestions on the manuscript. This project was financially supported by Conselho Nacional de Desenvolvimento Científico e Tecnológico-CNPq (485074/2012-5 and 306352/2014-1), Fundação de Amparo à Pesquisa do Estado do Rio de Janeiro-FAPERJ (E-26/103.285/2011 and E-26/111.296/2014), and Instituto Oswaldo Cruz (FIOCRUZ) (POM and PAEF). TSC, SFCN and BRT received grants from Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES).

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Submitted: 27 April 2017

Received in revised form: 20 July 2017

Accepted: 30 October 2017

Editorial responsibility: Diego Astúa de Moraes

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**Author Contributions:** RG and PSD conceived and designed the study, all authors carried out the field work, RG and TSC analysed the data, BRT identified the rodent species, all authors wrote the paper.

**Competing Interests:** The authors have declared that no competing interests exist.